THE JOINT CENTER FOR SATELLITE DATA ASSIMILATION

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NASA, NOAA, and the Department of Defense use common infrastructure and directed research to address the research-to-operations problem for satellite data assimilation.

The Joint Center for Satellite Data Assimilation (JCSDA) was established by the National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA) in 2001, with the Department of Defense (DoD) agencies becoming partners in 2002. The goal of JCSDA is to accelerate the use of observations from Earth-orbiting satellites in operational environmental analysis and prediction models for the purpose of improving weather forecasts, improving seasonal-to-interannual climate forecasts, and increasing the accuracy of climate datasets. Advanced instruments of the current and planned satellite missions do and will increasingly provide large volumes of data related to the atmospheric, oceanic, and land surface states. During this decade, the plan will result in a five order of magnitude increase in the volume of data available for use by the operational and research weather, ocean, and climate communities (see Fig. 1). These data will exhibit accuracies and spatial, spectral, and temporal resolutions never before achieved. JCSDA will help ensure that the maximum benefit from investment in the space-based global observing system is realized.

JCSDA will accelerate the use of satellite data from both operational and experimental spacecraft for weather and climate prediction systems. To this end, several activities have been undertaken. These include the advancement of data assimilation science by JCSDA through the establishment of the JCSDA Community Radiative Transfer Model (CRTM). The CRTM has benefited from continual upgrades,

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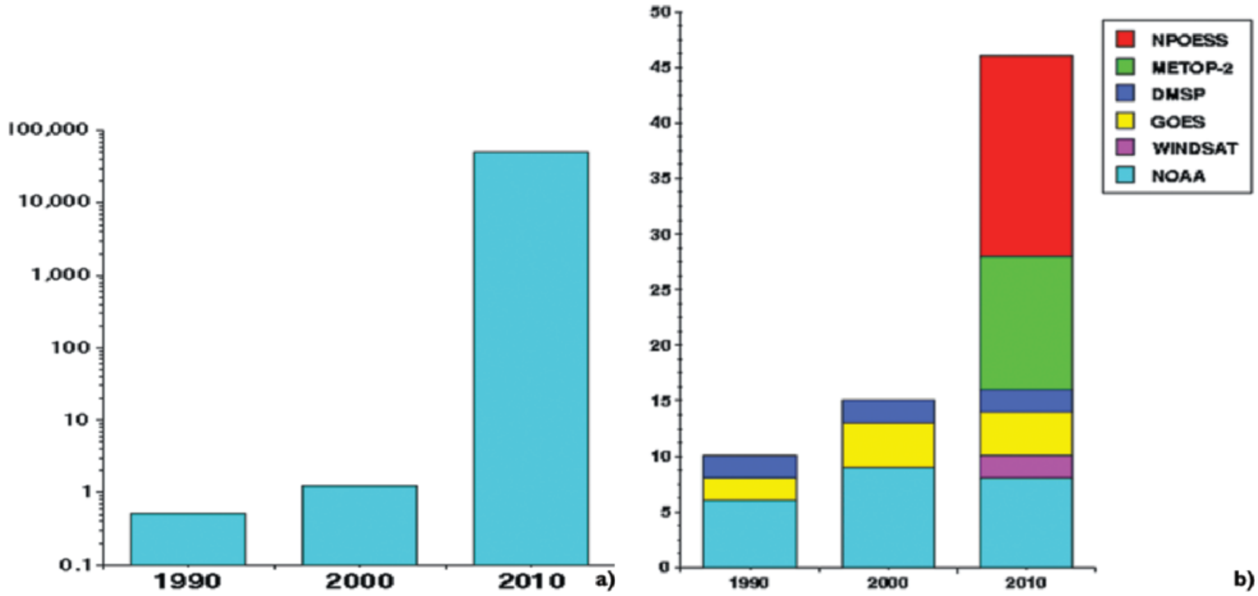

Fig. 1. (a) Daily upper-air observation count in millions as a function of time (1990–2010). (b) Satellite instrument numbers by platform as a function of time (1990–2010).

including the incorporation of the Atmospheric Infrared Sounder (AIRS) and snow, ice, and land emissivity models/statistical databases for improving the use of microwave sounding data over high latitudes. It has also included preparation for the use of data from the Meteorological Operational Polar Satellite's (METOP's) Infrared Atmospheric Sounding Interferometer (IASI), the Advanced Microwave Sounding Unit (AMSU), the Humidity Sounder for Brazil (HSB), the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager/Sounder (SSMIS) and the Challenging Mini Payload (CHAMP), and The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) global positioning system (GPS)-based radio-accultation systems. Real-time delivery of Earth Observing System (EOS) *Aqua* Advanced Microwave Sounding Radiometer-E (AMSR-E) data to numerical weather prediction (NWP) centers, and improved physically based sea surface temperature (SST) analyses have also been provided. Eighteen other research projects are also being supported by JCSDA (e.g., assimilation of cloudy radiances from advanced satellite instruments) to contribute to a state-of-the-art satellite data assimilation system. The work undertaken by JCSDA represents a key component of the Global Earth Observing System of Systems (GEOSS). In particular, data assimilation, data impact studies, Observing System Simulation Experiments (OSSEs), The Observing System Research and Prediction Experiment (THORPEX), and network design studies are key activities of GEOSS.

Another key activity within JCSDA has been to lay the groundwork for and to establish common NWP models and data assimilation infrastructure for assessing new satellite data and optimizing the utilization of these data in operational models. As a result of this activity, common assimilation infrastructure has already been established at NOAA and NASA. This has included the adoption of the Earth System Modelling Framework (ESMF) and use of the grid-point statistical interpolation (GSI) analysis system. There are also short- and longer-term plans involving the agencies related to 4D data assimilation.

Recent advances at JCSDA include the demonstration of the benefits to Northern and Southern Hemisphere forecasts from AIRS radiance assimilation using the National Centers for Environmental Prediction (NCEP) global forecast model, the demonstration of the benefits of Moderate Resolution Imaging Spectroadiometer (MODIS) polar atmospheric motion vector assimilation on global forecasts, and the beneficial impact from use of the CRTM in the modeling of sea ice and snow emissivity. These advances are summarized below.

BACKGROUND. An indication of the impact of satellite data on improving operational numerical weather forecasts is given in Fig. 2, which shows the anomaly correlation coefficient (ACC) for 500-mb height calculated for the NCEP 5-day forecast as a function of time. The correlation is between the observed and predicted deviations from the climatological 500-mb height field. A steady improvement in the ACC is evident, with a larger rate of improvement for the Southern Hemisphere. The noticeable improvements in the late 1990s are due, to a significant degree, to direct radiance assimilation and instruments such as the Advanced Microwave Sounding Unit (AMSU).

For example, the implementation of AMSU-A radiance assimilation in the Navy Operational Global Atmospheric Prediction System (NOGAPS) represented one of the most important advances to NOGAPS skill in a decade. The assimilation of these radiances in the Naval Research Laboratory's (NRL's) Atmospheric Variational Data Assimilation System (NAVDAS) substantially improved the height, wind, and temperature forecasts for both hemispheres at all forecast times, reduced tropical cyclone–track error forecasts by up to 25 Nm (Fig. 3a), and resulted in significantly fewer forecast busts (Fig. 3b).

Even with these recent improvements in forecast skills, there remains room for continued improvement, in particular toward decreasing the frequency of larger-than-normal forecast errors, or "busts" related to large errors in the initial model fields in areas where existing observing systems do not provide adequate coverage with accurate measurements of temperature, moisture, and wind. It is very clear that assimilation of satellite observations will make key contributions to that improvement. Furthermore, the improved global analyses based on the accelerated use of high-spectral-resolution observations will continue to allow models to expand useful prediction well into the 7–10-day range. As a result, there is a need for increasing the emphasis on satellite data usage in the data assimilation community, both in terms of introducing new and additional satellite data, and refining the assimilation methodologies for current and future observation systems. This need is a complex challenge whose solution will provide a considerable return on the investment made in the satellite observing network. Over the coming years, operational instruments with the capabilities of the current experimental Atmospheric Infrared Sounder (AIRS) will be launched. These instruments will provide data at spatial, spectral, and temporal resolutions vastly exceeding those of earlier instruments. This provides the NWP and data assimilation communities with new possibilities and new challenges. New possibilities arise, for example, because of the unprecedented vertical resolution provided by these instruments; new challenges will emerge because of the sheer volume of data that will be provided and because of many scientific questions that need to be answered to make optimal use of these remotely sensed observations.

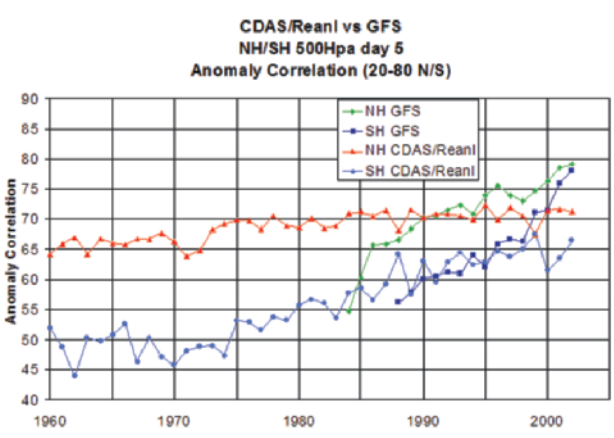

Fig. 2. Anomaly correlation coefficient (ACC) for 500-mb *Z* for NCEP 5-day forecast as a function of time. Red and blue (green and black) lines refer to fixed (evolving) model and assimilation system. Red and green (blue and black) lines refer to the Northern (Southern) Hemisphere.

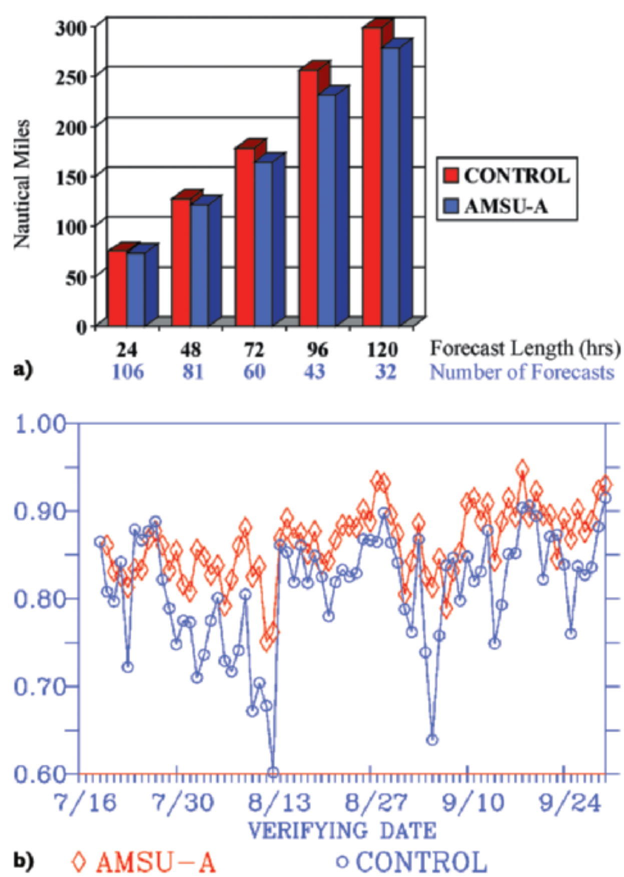

Fig. 3. (a) Tropical cyclone–track error forecasts with (AMSU-A) and without AMSU-A (control) in the NRL NAVDAS forecast model. (b) 500-hPa height anomaly correlation for NAVDAS with (AMSU-A) and without (control) 15 Jul–30 Sep 2003.

THE JOINT CENTER FOR SATELLITE DATA ASSIMILATION.

In April 2000, a small team of senior NASA and NOAA managers released a white paper (F. Einaudi et al. 2000, unpublished manuscript) containing plans to improve and increase the use of satellite data for global numerical weather models. The white paper provided a specific recommendation to establish what would be called JCSDA. This white paper came in response to a growing urgency for more accurate and improved weather and climate analyses and forecasts. These improvements could only be made possible by the development of improved models and data assimilation techniques, which allow models to utilize more and better-quality data. In 2001 JCSDA was established (L. Uccellini et al. 2000, unpublished manuscript); JCSDA expanded its partnerships to include the U.S. Navy and Air Force weather and oceanography agencies.

The cooperative agreement allows JCSDA's partners to take advantage of the science and technology resources of NOAA, NASA, and DoD to accelerate the use of existing and new satellite data. JCSDA also provides a focal point for the development of common radiative transfer models and infrastructure among the DoD, NOAA, and NASA partners. This shared approach to research and development activities will leverage available resources and will reduce the need for duplicated efforts within the various government agencies. NOAA has provided a centralized location for JCSDA administrative and information technology (IT) resources, while geographically distributed JCSDA components will be located in various JCSDA member organizations. Research projects may be conducted on site at JCSDA, partner agencies, and universities and other facilities. Support for JCSDA has also been provided by other organizations, for example, the National Science Foundation has supported staff at JCSDA to ensure they were ready to use COSMIC observations immediately after launch of the constellation.

The JCSDA is headed by a full-time director and has around 30 on-site scientific staff. It has a management oversight board (MOB) of agency representatives, which oversees its overall functioning. Participating agencies of JCSDA provide scientists who serve as scientific staff and technical liaisons. An advisory board and the Science Steering Committee provide external advice and review to the MOB and director, respectively.

All planning activity has been a collaborative effort among NASA, NOAA, and DoD, defining a process that ensures teamwork is a continuing attribute of JCSDA. Initial efforts have focused on defining a life cycle approach to data assimilation projects. Several critical elements have been defined. First, an end-to-end process begins with defining an instrument, then moves to characterizing the instrument's in-flight performance, developing algorithms and testing radiative forward transfer models for data assimilation, testing the impact of synthetic data, integrating the data into operational systems, and finally assessing the data's impact on analyses and forecasts. Second, a scientific review process by JCSDA personnel and the JCSDA Science Steering Committee provides feedback on each scientific project and determines if new systems are ready for implementation into operations. Third, a transition-to-operations plan ensures that new systems developed at JCSDA are transitioned smoothly, and JCSDA scientists participate in the overall implementation process to the extent needed.

JCSDA MISSION, GOALS, AND SCIENCE PRIORITIES.

The prime benefit from JCSDA will be improved weather and climate analyses, forecasts, and warnings and an extension of the time range of weather and climate forecasts, resulting in reduced losses of life and property and improved DoD mission effectiveness.

The mission of the Joint Center for Satellite Data Assimilation is to accelerate and improve the quantitative use of research and operational satellite data in weather and climate analysis and prediction models. Three goals support this mission. The first goal is to reduce from two to one year the average time for operational implementation of new satellite technology. The second goal is to increase the use of current satellite data in NWP models, and the third goal is to assess the impact of data from advanced satellite sensors on weather and climate predictions. With average satellite lifetimes of five years, *the first goal will result in an increase of 33% in productivity.* In the second goal, we emphasize the use of current satellite data because, for example, fundamental information from satellites associated with clouds and precipitation has not yet been optimally assimilated and the benefits of the current sensors to weather and climate predictions have not been maximized. The third goal will allow us to identify which observations have the most impact and to develop methods for appropriately selecting and assimilating those critical observations in situations where resources do not permit assimilation of all available observations.

To achieve these goals, the JCSDA has *initially* set the *five scientific priorities* discussed here.

Science priority I—Improve radiative transfer models. Atmospheric Radiative Transfer Modeling—The Community Radiative Transfer Model. Satellite radiances are not components of atmospheric state vectors predicted by NWP models. For radiances to be assimilated by NWP models, a relationship between the model state vectors and the observed radiances is required. This relationship is provided by forward radiative transfer models with the state vectors as input (see Fig. 4). In addition, the Jacobian vectors (or the derivative of radiance relative to the state vectors) are also needed for satellite data assimilation systems. Radiative transfer modeling uses atmospheric transmittance as the key input. The transmittance varies with the atmospheric conditions in a complicated way and its often computed through the line-by-line (LBL) models. Although LBL models are accurate, it takes considerable time to calculate transmittances for just a few atmospheres. To provide accurate transmittances in a timely fashion, JCSDA has generated and uses fast approximations commonly known as fast-forward models for specific instrument channels. Current fast models are discussed in Kleepsies et al. (2004).

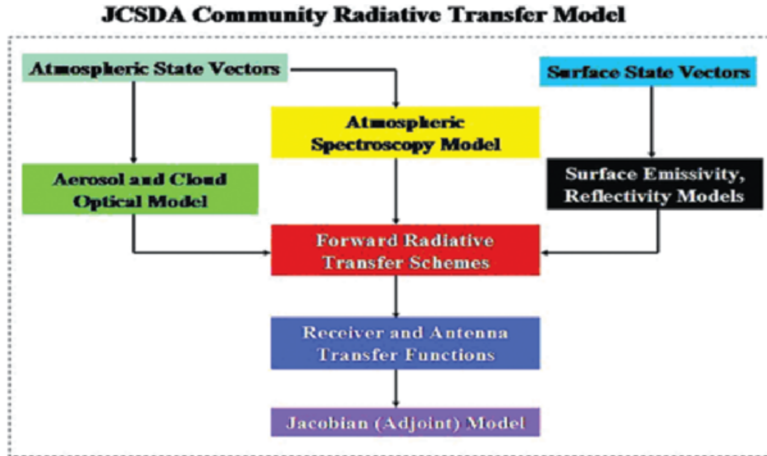

Fig. 4. Components of the JCSDA CRTM.

Transmittance models now need to consider more minor gases such as carbon dioxide, methane, and carbon monoxide, because the forecast models are making greater use of satellite measurements that are sensitive to them. Presently, transmittance models usually only include a number of "fixed" gases, water vapor, and ozone. Assimilating these measurements into forecasting models and predicting their distribution require transmittance models that include variations in theses gases. As the transmittance models become more accurate, the variations in retrieved temperature resulting from changes in minor gases become significant when they are ignored. For these reasons, future fast models must include the effects of these minor gases. In the short-wavelength regions near 4 μm, aerosols begin to have a minor but significant effect. Volcanic gases and aerosols can also affect the radiation at other wavelengths as well, and must be included in transmittance calculations.

To fully utilize the information of satellite measurements under all weather conditions for NWP, the forward-modeling capability needs to be enhanced to include both scattering and polarization processes (Fig. 4). Cloud-affected satellite radiances have not generally been assimilated into operational forecasting models, although the measurements contain considerable information pertinent to the atmospheric hydrological cycle. In the next decade, many advanced infrared and microwave sensors will be deployed in space, and their sensitivity to various atmospheric and surface parameters is significant. *The use of cloudy radiances in NWP models will ultimately enhance the impacts that have been demonstrated presently through clear radiance assimilation and will add to our knowledge of clouds, the surface, and the hydrological cycle.*

Surface emissivity modeling. Satellite observations in and around window regions of absorption spectra are affected by surface emissivity. Without a surface emissivity model or spectral emissivity database, measurements from advanced sounders, for example, may not be effectively assimilated into NWP models. As a critical part of a radiative transfer model (see Fig. 4), surface emissivity modeling should explain the variability of both emissivity and reflectivity. JCSDA is supporting theoretical and technological advances in quantifying the emissivity spectrum for various sensors covering the global environment.

Science priority II—Prepare for advanced operational instruments. A key activity of JCSDA is the development of the methodologies and associated software and hardware tools for assimilating data from the next generation of advanced satellite instruments. These instruments will be flying on NOAA, NASA, and DoD satellites, as well as other international spacecraft. The large number of advanced sensors will provide environmental data at spatial, temporal, and spectral resolutions never before achieved. A key performance measure for JCSDA will be a decrease in the time required to develop and transfer assimilation systems to NOAA, NASA, and the DoD for operational use for each new instrument. The development process will have pre- and postlaunch phases. As part of optimizing the use of current sensors and preparing for advanced operational instruments, JCSDA partners have in concert reviewed current and future instruments and assigned priorities for the use of their data. This has allowed an efficient preparation for, and transition of new observations into, operations. Currently, for example, there are around 35 satellite instruments used in the NCEP Operational Global Forecast System (GFS), with several others still in the transition phase.

Science priority III—Assimilating observations of clouds and precipitation. Assimilation of precipitation. Satellite precipitation estimates have two key strengths for data assimilation. First, they have a wide area of coverage, especially over the data-sparse oceans; second, they provide a means for adjusting the vertical profile of latent heating in the atmosphere, which is a quantity that typically cannot be obtained using current in situ coverage. This adjustment may be accomplished by inverting the convective parameterization scheme of the model and adjusting the vertical profiles of latent heating and, consequently, temperature and moisture (Krishnamurti et al. 1984; Hou et al. 2000). This process will increase the consistency between the model precipitation and the observed precipitation during a dynamic assimilation period. Similar adjustments can be made to vertical profiles of moisture for grid-scale precipitation.

A number of issues remain to be resolved, however, to make optimal use of precipitation data in NWP models, including the current accuracy of precipitation estimates from satellite data and the lack of error characterization of satellite precipitation estimates at model scales in a form that can be used to develop appropriate weighting for assimilating the data. In addition, convective schemes still do not accurately depict the relationship between latent heating and precipitation, and a single value (precipitation rate) cannot by itself adequately constrain and adjust vertical profiles of latent heating (and thus temperature and moisture).

Direct assimilation of radiances in cloudy and precipitation conditions. Direct radiance assimilation under cloudy and precipitating conditions may be improved by detailed information on the profiles of cloud microphysical variables that can be explicitly simulated by the NWP models. Cloud schemes based on Zhao and Carr (1997) and Ferrier et al. (2002), for example, have been implemented into NCEP global and regional (Eta) forecast models, respectively. Similarly, the cloud scheme based on Schmidt (2001) and Chen et al. (2003) has been implemented into the navy Coupled Ocean–Atmosphere Mesoscale Prediction System (COAMPS) mesoscale model. These schemes run slightly different physical packages, but predict water mixing ratios associated with various condensates within the model grids. In principle, these cloud schemes can resolve all cloud condensates only when the model resolution is increased to less than a few kilometers. At larger resolutions, the forecast model must use the cumulus parameterization scheme to determine the clouds and precipitation associated with convective motion.

To estimate the quality of the model-predicted cloud condensates, observational datasets are required to characterize the errors of the forecast model cloud water/ice content. Retrievals from satellite passive sensors may be used for the assessment of model errors in the column-integrated water (Weng et al. 1997); however, it was difficult to characterize the errors in the profiles of cloud condensates predicted by forecasting models before the data from satellite active sensors, such as CloudSat (Stephens et al. 2002), became available.

The errors of forward radiative transfer models in cloudy conditions also need to be characterized. At microwave frequencies of less than 60 GHz, the cloud optical parameters are not sensitive to the particle size and the errors of the forward model may be characterized. However, in microwave window channels, the simulations of cloudy radiances are complicated by the variability in surface emissivity. Understanding the error characteristics at higher microwave frequencies and visible/infrared wavelengths remains challenging because the radiative transfer processes are more sensitive to particle size distribution, shape, bulk volume density, and phase (Evans and Stephens 1995; Weng and Grody 2000). The simulations are also affected by the vertical structure of clouds in various phases. It is essential that detailed observational data of cloud microphysical parameters are available in order to quantify the forward model errors.

Science priority IV—Assimilation of land surface observations from satellites. NWP models can use satellite-based observations to provide model lower boundary conditions in two ways—in the specification of surface boundary conditions and as forcing in uncoupled model surface physics schemes. Lower boundary conditions for NWP models over land surfaces include most of the properties of vegetation, soil, and snow–ice cover. Quantities such as green vegetation fraction, leaf-area index, vegetation class, soil albedo, surface emissivity, and snow cover and snowpack parameters (snow-water content, snow depth) can be estimated from satellite measurements. Because some of these characteristics change on time scales from hours to days, real-time estimates from satellite observations are required. Satellite estimates of components of the surface radiative fluxes and precipitation may be used to force uncoupled land data assimilation systems (e.g., LDAS). Near-real-time estimates of insulation, downward longwave radiation, and surface temperatures are required.

Land surface states are also critical to the initialization of seasonal climate forecasts, especially the memory in the system associated with soil moisture and snow. Global retrievals of snow mass, snow cover, and soil moisture are available from various research satellite sensors, including AMSR-E and MODIS on the *Aqua* satellite. NASA's Global Modeling and Assimilation Office (GMAO) has developed a system to assimilate these data into the GMAO catchment land surface model using an ensemble Kalman filter, and is in the early stages of incorporating that system into the GMAO coupled seasonal forecast system. As with other data types, an issue to be addressed is the observational error characterization and biases between different data sources and models (e.g., Reichle et al. 2004; Reichle and Koster 2004).

Science priority V—Assimilation of satellite oceanic observations. Satellite-derived observations of the marine interface are increasingly being used in data assimilation systems. In 1990, the U.S. Navy began assimilating marine surface wind speeds from the Defense Meteorology Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I). Today, those wind speeds are used operationally by the navy, including for regional assimilation, and by NCEP in the Global Data Assimilation System (GDAS). In addition, wind vectors over the oceans are retrieved directly from NASA Quick Scatterometer (QuikSCAT) data and are operationally assimilated into GDAS, NOGAPS, and the navy's mesoscale model, COAMPS. Recently, attention has turned to the marine surface wind measurements from WindSat. A recent evaluation at NRL Monterey shows that, when comparing WindSat and QuickSAT Environmental Data Records (EDRs) to independent NOGAPS analyses (which assimilated neither data source), WindSat can produce data that fit the independent analyses better then QuickSCAT can. This and related assimilation work with WindSat lay the groundwork for future assimilation of microwave imager/sounder observations in the National Polar-orbiting Operational Environmental Satellite System (NPOESS) era.

Recently at JCSDA, J. Derber and X. Li (2004, personal communication) have developed a physically based variational assimilation methodology for deriving accurate SSTs from clear radiances. In the longer term, this method will allow sea surface temperatures to be consistent with both atmospheric and skin temperatures derived from multispectral radiance observations. In particular, it will allow for an optimal combination of infrared and microwave data in the generation of SST. The system has recently completed a real-time trial at NCEP and is now operational.

While three-dimensional analyses of ocean temperature have also been around for decades, these efforts were limited by the lack of sufficient subsurface ocean measurements. Although the Tropical Atmosphere–Ocean (TAO)/Triangle Trans-Ocean Buoy Network (TRITON) mooring array, deployed in 1984 and completed in 1994, has had a substantial impact on the forecast skill of equatorial Pacific sea surface temperature and the associated climatic oscillations, the array is sparse and, even with other in situ data, provides inadequate coverage outside the equatorial Pacific, where floats and bathythermographs (XBTs) provide the primary sources of what is still a very sparse dataset of in situ measurements. Hence, the sea surface height (SSH) information provided by satellite surface altimetry is a critical source of information on ocean variability. Even so, the use of altimeter information to infer the subsurface ocean variability is not without difficulty, particularly with inadequate information of the geoid. Several different methods have been developed over the years for using the altimeter to infer subsurface ocean variability, from statistical methods that generate synthetic temperature–salinity profiles from analyzed SST and SSH and historical data records (Hurlburt et al. 1990; Fox et al. 2002) to methods that directly assimilate the SSH anomalies (Cooper and Haines 1996). The developments at NCEP and NASA, by the navy, and in the external contributions to JCSDA are focused on how to make the best use of this data source for ocean data assimilation and how to characterize the observational errors in SSH in terms of representativeness (e.g., Kaplan et al. 2004).

The navy has implemented a three-dimensional multivariate optimum interpolation system [Navy

Coupled Ocean Data Assimilation (NCODA)] that analyzes temperature, salinity, dynamic height, currents, sea ice, and significant wave height on a global or regional scale (Cummings 2005), with research at NRL also focused on development of four-dimensional variational methods for ocean application (Smith and Jacobs 2005) and the use of ensemble transform Kalman filter–derived flow-dependent error covariances (Bishop et al. 2001). The NCEP Global Ocean Data Assimilation System (GODAS) is a three-dimensional variational data assimilation (3DVAR) method that is an extension of the work of Derber and Rosati (1989) (e.g., Behringer et al. 1998). At NASA GMAO, multivariate forecast error statistics are derived from an ensemble Kalman filter to project the information from the surface data to the subsurface ocean (e.g., Keppenne and Rienecker 2002, 2003). Related developments are focused on the improvement of assimilation systems to take into account systematic errors in the forecast models, using techniques following Dee and Da Silva (1998). Several other oceanic data assimilation projects are underway and may be viewed on the JCSDA Web site (online at www.jcsda.noaa.gov). In particular, NCEP and NASA GMAO have developed ocean data assimilation systems to initialize the ocean as part of their coupled seasonal forecast systems, while the navy continues to concentrate on the short-range real-time coupled air–ocean analysis and forecast problem. Of course, advances in the optimum assimilation of ocean measurements from satellites benefits all of these goals.

RECENT ADVANCES. *The Community Radiative Transfer Model.* JCSDA has made significant advances in formulating CRTM. For atmospheric transmittance calculations, the gas absorption coefficients are predicted with the atmospheric parameters and polynomial expansions of the absorber amount (Kleepies et al. 2004). This approach significantly reduces the coefficients that reside in computer memory and preserves the accuracy. Now, only 70 coefficients instead of 1,800 are needed to compute the transmittance at each channel. The transmittance is calculated with a correction term to account for the average strengths of gaseous absorption within the instrument bandwidth. In addition, new predictors are added to improve the ozone absorption. Figure 5 displays the performance of a recent fast transmittance model Optical Path Transmittance-V7 (OPTRAN-V7) and compares it with the recent operational model for 20 High-Resolution Infrared Radiation Sounder (HIRS) channels.

Studies have also been completed to develop a fast microwave radiative transfer model, which includes the scattering and polarization of clouds, precipitation, and aerosols (Liu and Weng 2002; Weng and Liu 2003). Recent work has also addressed the modeling of ice and snow emissivity, and trials have shown improvement in high-latitude forecasts from NCEP's Global Forecast System. Figure 6 shows the improved geopotential height anomaly correlation at 850 hPa for the GFS with the new emissivity model, compared to the control.

Aqua applications: AIRS data thinning, distribution, and impact/MODIS winds. JCSDA has successfully distributed AIRS data to the world's major NWP centers. An initial constraint in providing AIRS radiances in near–real time to the main NWP centers is data volume size. AIRS/AMSU/Humidity Sounder for Brazil (HSB) level 1b data are about 2.5 Gb for a 100-minute orbit, compared to the approximately 14 Mb per orbit from Advanced Television Infrared Observation Satellite (TIROS) Operational Vertical Sounder (ATOVS) (HIRS ~4.5 Mb, AMSU-A ~2 Mb,

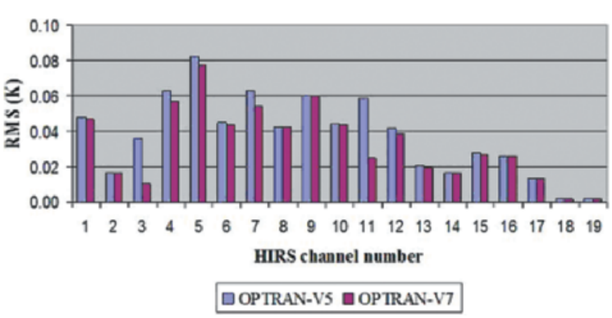

Fig. 5. Latest optical path of gaseous transmittance model performed at 19 HIRS channels.

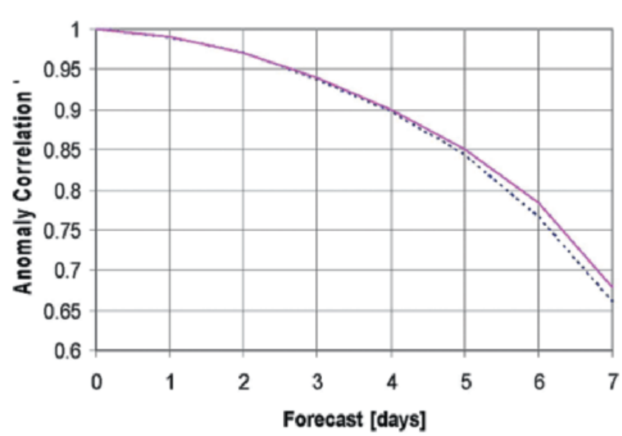

Fig. 6. Impact of sea ice and snow emissivity models on the GFS 24-h forecast at 850 hPa (1 Jan–15 Feb 2004, 60°N–90°N); the pink curve shows the ACC with new snow and sea ice emissivity models).

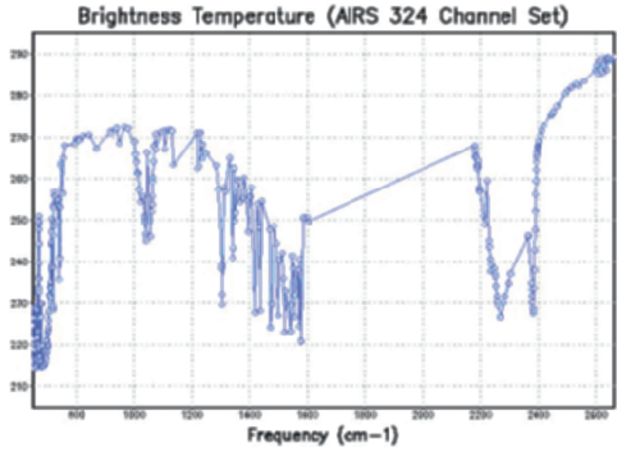

Fig. 7. Spectral locations for 324 AIRS thinned channel data distributed to NWP centers.

AMSU-B ~7.5 Mb). Each 6-min granule consists of 90 AIRS and HSB fields of view (FOVs) per scan line and 30 AMSU-A FOVs per scan line. There are 135 AIRS and HSB scan lines per granule, and 45 AMSU-A scanlines per granule (Goldberg et al. 2003; Aumann et al. 2003). A simple solution to the relatively high volume of AIRS/AMSU/HSB is to increase the available communication bandwidth, but that option is costly and at present most NWP centers cannot assimilate all of the data due to computational costs and limitations in data storage. As a result the AIRS/AMSU/HSB data are thinned into several subdatasets. Visually, each AMSU-A FOV, which has a spatial resolution of approximately 42 km on the Earth near the nadir view position, contains a 3 × 3 array of AIRS and HSB FOVs, each with a spatial resolution of approximately 14 km. The AIRS and HSB FOVs are spatially coincident. The data are thinned by subsampling FOVs and channels. A subset of about 324 channels (see Fig. 7) is extracted from the center AIRS FOV of the 3 × 3 array, as well as all 15 AMSU-A channels and the 4 center channels from the HSB FOV. Each granule has two files, each containing data from alternate center FOVs. The size of each file is about 0.5 Mb. An orbit of data is about 16 Mb, which is only about 15% greater than the full ATOVS data. The method of channel selection is described in Suskind et al. (2003). The single FOV-thinned radiance dataset is the core data that are used by most NWP centers assimilating AIRS radiances. The files are available in Binary Universal Form for the Representation of Meteorological Data (BUFR) and Hierarchical Data Format (HDF).

The result of this distribution is that several key centers have documented their utility for NWP, and included the radiances in their operational data

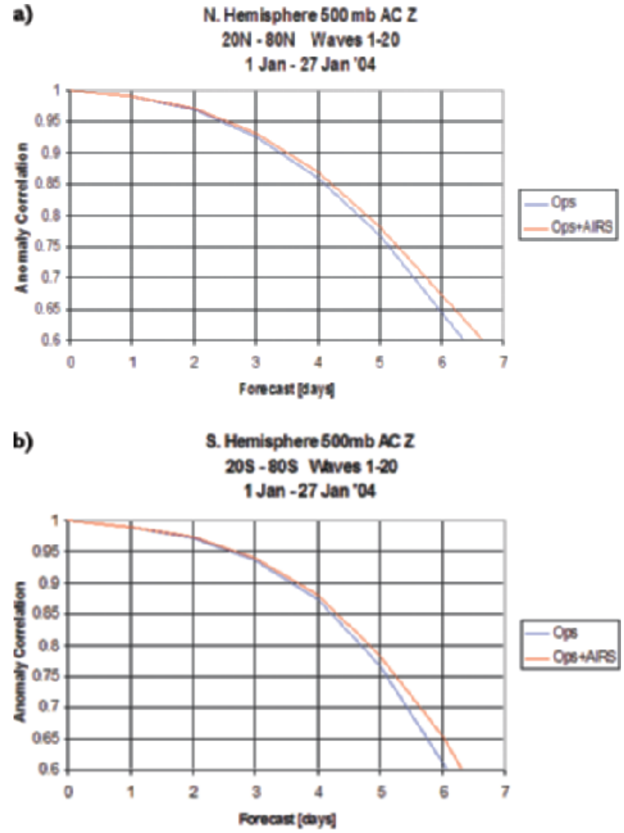

Fig. 8. (a) The impact of AIRS data on GFS forecasts at 500 hPa (20°N–90°N, 1–27 Jan 2004); the pink (blue) curve shows the ACC with (without) AIRS data. (b) The impact of AIRS data on GFS forecasts on 500 hPa (20°S–90°S, 1–27 Jan 2004); the pink (blue) curve shows the ACC with (without) AIRS data.

stream. Evidence of a significant positive impact of AIRS data on global forecasts in *both the Northern and Southern Hemispheres* has been recorded in trials at JCSDA, where all AIRS FOVs have been used. The impact can be seen in Figs. 8a and 8b (Le Marshall et al. 2005a,b). The improvement in forecast skill at 6 days is equivalent to gaining an extension of forecast capability of several hours. This improvement is quite significant when compared to the rate of general forecast improvement over the last decade. A several-hour increase in forecast range at 5 or 6 days normally takes several years to achieve at operational weather centers. Operational use of these AIRS data has been enabled by the enhanced computing resources associated with the recent (31 May 2005) operational upgrade at NCEP.

A number of studies have also been completed in relation to the use of data from the MODIS instrument on *Aqua*. Winds generated using sequential MODIS images over polar regions (Daniels et al. 2004) have been used in a series of impact studies

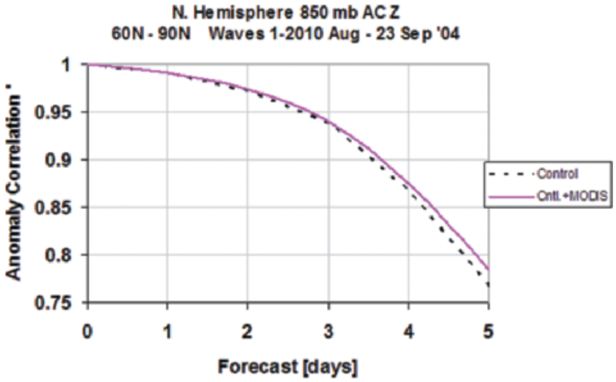

Fig. 9. Impact of MODIS AMVs on the operational GFS forecast at 500 hPa (60°N–90°N, 10 Aug–23 Sep 2004); the pink (dashed) curve shows the ACC with (without) MODIS AMVs.

using NCEP's operational global forecast model (Le Marshall et al. 2004). Impacts in both northern and southern high latitudes were positive even though winds were only assimilated up to the second-to-last analysis to simulate existing operational data availability (Fig. 9). These results are consistent with the results seen at NRL, which is where operational assimilation of the MODIS winds in NOGAPS began in October 2004.

Precipitation and cloud data assimilation. Satellite precipitation products are assimilated at JCSDA member institutes. At the Environmental Modeling Center (EMC), the GDAS makes use of instantaneous rain rates derived from SSM/I and Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) brightness temperatures. The Eta Model Data Assimilation System (EDAS) uses these observations as available over its North American domain, plus total column water vapor (TCWV) from the Geostationary Operational Environmental Satellite (GOES) (over land) and SSM/I (over water). Overall, the greatest effect of rain-rate assimilation is on the reduction of excessive precipitation. Increases in the simulated rain rates are less pronounced.

At NASA GMAO, Hou et al. (2000) have also assimilated the TMI-derived surface rainfall and total precipitable water (TPW) into the Goddard Earth Observing System (GEOS) global analysis. A unique feature of the GEOS data assimilation system is that it uses the incremental analysis update (IAU) developed by Bloom et al. (1996), which virtually eliminates the spinup problem. The control variables are analysis increments of moisture and temperature within the IAU framework. The procedure minimizes the least squares differences between the TMI observations and the corresponding values generated by the column model averaged over the 6-h analysis window. The minimization procedure is one-dimensional, but the evaluation of the cost function involves a 6-h time integration of the time-averaged rainfall and TPW.

THE FUTURE. JCSDA activities are divided into directed research and development/infrastructure activities, "in kind" internal investment by the JCSDA partners, and proposal-driven projects. Initially, infrastructure activity will maintain focus on the development and maintenance of a scientific backbone for the JCSDA community fast radiative transfer model, a community emissivity model, and an infrastructure for performing assimilation experiments with real and simulated observations from new and future instruments. Internal investment in data assimilation research will be coordinated through JCSDA and developments will be shared among partners for operational application. Finally, proposal-driven scientific projects will be an important mechanism used to accelerate the transition of research and technological advances in satellite data assimilation by planned incorporation of new codes into the NASA/NOAA/DoD operational data assimilation systems and by performance of preliminary testing with these systems. Initial JCSDA projects in the past few years have solidified NOAA, NASA, and DoD collaborations on AIRs, QuikSCAT, TRMM, and the NPOESS preparatory missions. Furthermore, JCSDA will facilitate additional collaboration in areas deemed potentially important for improving climate, weather, and ocean prediction, such as in the utilization of the Infrared Atmospheric Sounding Interferometer (IASI); Cross-Track Infrared Sounder (CrIS)/Advanced Technology Microwave Sounder (ATMS), Geostationary Infrared Fourier Transform Spectrometer (GIFTS), and GPS radiooccultation data and will support an examination of the utility of geostationary microwave observations.

A primary goal of JCSDA in next few years is to continue to lay the groundwork and establish a common data assimilation infrastructure for assessing new satellite data and optimizing the utilization of these data in operational models. An important step is to make versions of operational global/regional data assimilation systems accessible to JCSDA research collaborators, and to include the establishment of real-time communications to JCSDA computers and real-time databases and observation-handling algorithms for continued assessment of new instruments.

A most important activity for JCSDA is planning in relation to the form of the next-generation assimilation systems to be used by the partners. A strategic planning activity is already underway detailing the optimal form of the infrastructure for the next generation of modeling and assimilation systems. Planning and activity involves the use of the 4D variational approach for data assimilation.

In summary, by 2007 JCSDA deliverables will include the development of a community forecast and data assimilation system for both global- and regional-scale applications. The system will be linked to the research community through the U.S. Weather Research Program (USWRP) and will serve as the primary mechanism for infusing research and operational satellite data into NCEP, GMAO, and DoD operations.

In conclusion, JCSDA has made a strong start since its inception in 2001. This has been vital, because the strength of satellite data assimilation in JCSDA is central to the quality of future operational weather, climate, and environmental analysis and forecasting in the United States. As a result, every effort is being made by the partner organizations to work effectively together for the common good.

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